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IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF WYOMING

Biodiversity Conservation Alliance and Sierra Club,	)	
Plaintiffs,	)	Case No. 04CV 361-B
v.	)	
Mountain Cement Company,	)	
Defendant.	)	

EXPERT WITNESS REPORT OF RALPH L. ROBERSON ON BEHALF OF THE DEFENDANT MOUNTAIN CEMENT COMPANY

Defendant Mountain Cement Company files the attached expert witness report of Ralph L. Roberson, and pursuant to the Court's Unopposed Motion and Stipulated Order Extending Deadlines in Amended Order On Initial Pretrial Conference.

DATED this 15th day of August, 2005.

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CERTIFICATE OF SERVICE

I, Jason M. Tangeman, certify that a copy of the above and foregoing pleading was served on Plaintiffs by placing a copy of the same in the U.S. Mail, postage prepaid and addressed as follows on August 15th, 2005:

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UNITED STATES DISTRICT COURT
DISTRICT OF WYOMING

BIODIVERSITY CONSERVATION ALLIANCE and SIERRA CLUB RESPONSIBILITY,	)	
Plaintiffs,	)	**CIVIL ACTION FILE**
v.	)	**NO. 04CV-361-B**
MOUNTAIN CEMENT COMPANY	)	
Defendant.	)	

REPORT OF RALPH L. ROBERSON
FOR MOUNTAIN CEMENT COMPANY

August 2005

Ralph L. Roberson

Ralph L. Roberson

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I. STATEMENT OF COMPLIANCE WITH THE FEDERAL RULES OF CIVIL PROCEDURE

The following is a list of the items provided in my report as required by the Federal Rules of Civil Procedure:

- This report contains my opinions and conclusions, as well as the basis and reasons for those opinions and conclusions.

- Part II contains a statement of my qualifications, and Appendix B contains my resume, including a listing of publications and presentations. During the preceding 4 years I have testified at the following trial:

  Grand Canyon Trust et al. v. Public Service Company of New Mexico, No. CV 02-552 BB/ACT (New Mexico)

  And I have given depositions in the following two cases:

  United States et al. v. Ohio Edison et al., No. C2-99-1181 (S.D. Ohio)
  Sierra Club, et al. v. NREPC, et al., File Nos. DAQ-26003-037 and DAQ-26048-037 (Kentucky Administrative Proceeding)

- RMB Consulting & Research, Inc. is being compensated at the rate of $200 per hour for the time I spend on this project. Payment is not contingent on my findings or the outcome of this matter.

Since discovery is ongoing in this case, I reserve the right to supplement my report. I also reserve the right to use any exhibits or documents considered, relied upon, identified or used by any other witness in this case.

II. QUALIFICATIONS

I received my Bachelors and Masters degrees in mechanical engineering from the University of Virginia. I am a registered professional engineer and president of RMB Consulting & Research, Inc. I have approximately 35 years of experience in analyzing air pollution emission standards, conducting air pollution measurements, and assessing the performance of air pollution control technology. My recent experiences include providing technical assistance to electric utility companies in complying with consent decree requirements that mandate the purchase, installation and operation of particulate matter (PM) and mercury (Hg) continuous emission monitors (CEMS). I independently conducted a case-by-case mercury MACT analysis, and the results of my analysis are reflected in a power plant construction permit. Since 1975, I have reviewed, analyzed and provided technical comments on every rule proposed by EPA that affects continuous emission monitors and continuous emission monitoring requirements for power plants and other industrial sources. In 1983, I was the principal author of *Continuous Emission Monitoring Guidelines*, a document published and still being used and updated by the Electric Power Research Institute (EPRI). For the past decade, I have worked extensively to develop the use of state-of-the-art statistical techniques for (1) estimating emissions and analyzing emission data; (2) determining achievability of emission standards; and (3) assessing impacts on ambient air quality.

III. PURPOSE

I, Ralph L. Roberson, with RMB Consulting & Research, Inc. (RMB) was retained on behalf of Mountain Cement Company ("MCC") to provide expert opinion on (1) the two primary methods of measuring opacity (i.e., EPA Reference Method 9 and continuous opacity monitoring systems (COMS)) and (2) a compliance assurance monitoring (CAM) Plan for Kiln No. 2. The MCC facility operates under its Title V Operating Permit and the laws and regulations of the State of Wyoming.

The MCC facility produces Portland cement using two coal-fired kilns and various other process components including raw mills, clinker coolers, and material handling equipment. In simple terms, the Portland cement process involves blending limestone with shale or clay and iron and grinding the material into a fine powder, which is called raw meal. The raw meal is fed into a rotary kiln, which uses coal to generate the temperatures necessary to form clinker. The clinker is cooled, mixed with gypsum and ground into a fine power, which is Portland cement.

In this report, I present a comparison of the two opacity measuring methods, the resulting impact on the stringency of the opacity standard applicable to MCC's plant located in Laramie, Wyoming when using periodic readings (i.e., Method 9) versus the use of continuous data (i.e., COMS), and other technical issues related to monitoring opacity from flue gas stacks. I also present an analysis of the opacity and particulate matter (PM) correlation in MCC's CAM Plan and the problems with using COMS data to predict particulate matter emission rates. When MCC renewed its Title V Operating Permit, the Wyoming Department of Environmental Quality (WDEQ) required a CAM Plan for emission points with pollution control technology, including Kiln No. 2. For the Kiln No. 2 CAM Plan, MCC submitted a "loose" mathematical relationship between stack opacity and hourly PM emission rates. I use the word, "loose" because (1) the CAM Plan did not utilize all available data and (2) no statistical analysis of the relationship was performed. A straightforward statistical analysis of the data would reveal the huge variability in the opacity/PM emission rate relationship.

IV. SUMMARY OF CONCLUSIONS

In my opinion, an emission standard consists of at least three essential, interrelated elements: (1) the numerical limit, (2) the averaging time, and (3) the compliance measurement method and/or frequency. Changing or modifying any one of the elements without making a compensating change in the others can significantly alter the stringency of any emission standard. In my opinion, because of its original development as a "periodic" standard, the Wyoming opacity standard, when enforced with COMS data, is considerably more stringent than the limit when enforced with periodic Method 9 observations. This principle will be discussed in detail in subsequent sections of my expert report. Moreover, in recognition of this principle, a number of states have or are in the process of amending their visible emissions rules to adjust the stringency to account for the use of COMS data. It is my understanding that Wyoming has a practice that is similarly effective. That is, the Wyoming DEQ follows EPA's High Priority Violations policy for all major sources. Consistent with that policy, WDEQ takes no enforcement action if opacity exceedances measured by COMS occur less than 5 percent of the operating time in any one quarter or less than 3 percent of operating time in two consecutive quarters.

Wyoming regulations allow the use of "credible evidence" or information to determine compliance but only if such evidence or information is relevant to whether the source would have been in compliance with applicable emission limits *if* the appropriate compliance test had been performed. MCC's permits specify that compliance with the PM limit for Kiln No. 2 be determined annually by conducting a stack test using EPA Reference Method 5. It is also my opinion that in the absence of substantial data that establishes a more robust relationship between COMS data and Method 5 data for MCC Kiln No. 2, it cannot be said with reasonable certainty that any given COMS data are credible evidence of failing a PM compliance test. Therefore, in my opinion, without such robust data, COMS data cannot be the sole basis for determining non-compliance with a PM emission standard that requires averaging the results from three independent, 1-hour sampling runs using EPA Method 5.

V. THE REPORT

1. Overview of Types of Emission Standards

Emission standards developed by regulatory agencies generally fall into two categories: (1) periodic standards – in which the evaluation of the source and the control equipment is based on limited periodic "snapshots" of emissions using short-term tests performed during representative operating conditions (e.g., EPA Reference Method 5 tests for PM emissions, EPA Reference Method 9 for visible emissions); and (2) continuous standards – in which the evaluation of the source and of the control technology is based on data obtained from continuous monitoring, that is, data collected during all operating conditions.

The primary characteristic of a "periodic" standard is that it is developed from the analysis of a limited data set collected during representative operating conditions. Periodic emission tests cannot quantify long-term variability in the operation of a source or in the operation of any control technology.[1] Emission standards developed from such periodic tests are therefore not designed to be monitored on a continuous basis. Thus, in my opinion, data obtained from continuous monitoring systems, such as COMS, should not be used as a measure of compliance with emission standards based on periodic tests such as Method 9 for opacity and Method 5 stack tests for PM emissions. In contrast, "continuous" standards that are developed based on long-term, continuous emissions data allow the variability of both the source and the control technology to be factored into the setting of an emission standard.

When short-term tests are used to collect the data for the development of "periodic" standards, the compliance method specified for such standards is generally the same periodic test performed under "representative" (but not all) operating conditions. Similarly, when continuous data are used to develop "continuous" standards, the continuous method (e.g., a continuous emission monitor) is generally specified for determining compliance with those standards. From time to time, regulatory agencies are faced with a situation in which a continuous method for monitoring emissions from a source becomes available long after a standard based on periodic test data has been established. In such situations, the application of the continuous method to determine compliance with a periodic standard would make the standard more stringent. To maintain the same stringency, agencies convert the "periodic" standard to a "continuous" standard before requiring the use of the continuous method for determining compliance. In making this

[1] Throughout this report, when I use the phrase, *variability*, with respect to the operation of a source, I am referring to the fact that, in my opinion, no process or piece of equipment operates as designed 100 percent of the time. In

conversion, agencies recognize that the stringency of an emission limit is determined not just by the numerical value of the standard but also by the averaging time associated with the numerical limit and the method used to make emission measurements. Agencies generally convert a "periodic" standard to a "continuous" standard by adjusting the averaging time or by providing for de minimis relief periods during which excursions above the numerical limit are excused. The examples provided below illustrate this point in the context of EPA's rulemaking process for New Source Performance Standards (NSPS) under the Clean Air Act and State agency revisions to opacity standards as a result of the availability of COMS data.

2. Interrelationship of the Elements that Make-up Emission Standards

As previously stated, an emission standard consists of at least three essential, interrelated elements: (1) the numerical limit, (2) the averaging time, and (3) the compliance measurement method and/or frequency. The following examples taken from EPA rulemaking actions illustrate the Agency's recognition that altering any one of the interrelated elements of an emissions standard without making a compensating adjustment can affect the stringency of the underlying standard. Section V.5 of this Report will provide similar examples of regulatory actions, taken at the state level, that reflect acknowledgment of the impact of measurement frequency on the stringency of an emission standard.

2.1 Averaging Time

The interrelationship of numerical emission limits and averaging time is illustrated by EPA's rulemaking efforts in developing standards for new utility boilers in 40 CFR 60, Subpart D. EPA proposed and promulgated Subpart D in 1971.[2] At that time, EPA's data for developing emission standards were limited to periodic, snapshot measurements. EPA analyzed these data and set standards for PM, opacity, sulfur dioxide (SO_2) and nitrogen oxides (NO_x). To be consistent with the supporting data (and recognizing that continuous measurement technology was still under development), EPA specified compliance demonstrations be based on the periodic application of manual test methods to be conducted under representative operating conditions. In contrast, when EPA undertook revising the NSPS in the late 70's, the Agency decided it wanted to use continuous data for its SO_2 and NO_x emission standards. Accordingly, EPA used continuous emission monitors (CEMS) to collect the background data, conducted a rigorous statistical analysis of the data, and concluded that rolling 30-day averages were appropriate for

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fact, processes and equipment are subject to breakdowns, malfunctions, and other natural perturbations.

[2] Subpart D applies to fossil fuel-fired steam generators (i.e., boilers) for which construction commenced after

the numerical emissions limits that the agency had selected.

In October 1983, EPA proposed to change the compliance method for the Subpart D SO_2 NSPS from a periodic method to a continuous method.[3] At the heart of EPA's proposal was a switch from periodic measurements (i.e., EPA Method 6) to continuous emission measurements (i.e., CEMS). When considering this change to the measurement procedure, EPA recognized that it also needed to address the issue of averaging time. After reviewing the underlying database, especially the data pertaining to the sulfur content of coal, EPA concluded that a 30-day rolling average would be the appropriate averaging time to maintain consistency with the Subpart D SO_2 NSPS as it was promulgated in 1971. In its October 1983 proposal, EPA produced two tables that clearly illustrate the relationship between numerical limits and averaging times. Table 1 in EPA's proposal presented the range of average sulfur concentration in coal required to meet the 1.2 lb/10^6 Btu emission limit as a function of averaging time. Table 2 listed the U.S. low-sulfur coal reserves that would be expected to comply with various mean sulfur concentrations listed in Table 1. When Tables 1 and 2 are read together, it is apparent that a short-term (e.g., 3-hour) interpretation of the NSPS would severely limit the supply of compliance coal. However, on a longer-term basis (i.e., 30-day rolling average), about 25 percent of the known U.S. coal reserves could comply with the 1.2 lb/10^6 emission limit. Since this outcome was the Agency's original intent of the NSPS, EPA concluded that a 30-day rolling average would be the appropriate averaging time to couple with continuous SO_2 monitoring data. Although EPA never finalized this rulemaking, the Agency's technical analysis clearly quantifies the relationship between numerical limits and averaging times. Since the revisions to Subpart D were not finalized, the SO_2 standard in this rule remains a periodic standard.

Another example of the relationship of averaging time and stringency of an emission standard can be found in the SO_2 portion of the NSPS proposed by EPA for fluid catalytic cracking unit (FCCU) regenerators at petroleum refineries. In its proposal, EPA specified a 3-hour averaging time for the SO_2 emission standard for new, modified, and reconstructed FCCUs.[4] Commenters stated that the averaging time should be increased because 3 hours did not provide adequate time to adjust parameters, to account for the natural variability of the operating process as well as the air pollution control technology, and thus assure compliance with the proposed emission standard at all times. In promulgating the final rule, EPA stated that it had statistically analyzed the long-term variability of SO_2 emissions from FCCUs by conducting a time series analysis of continuous emission data from a recent EPA study. EPA concluded that the averaging time did,

August 17, 1971.

[3] 48 Fed. Reg. 48960 (October 21, 1983).

indeed, need to be lengthened in order for the numerical limit to be consistently achieved with the use of continuous emission monitors. Accordingly, EPA revised the proposed averaging time for the SO_2 emission standard from 3-hours to 7-days.[5]

2.2 Compliance Measurement Methods

The relationship of the stringency of an emission standard and measurement procedure (e.g., measurement frequency) is illustrated in EPA's NSPS rule for kraft pulp mills (i.e., paper mills). The preamble to that rule also provides an excellent discussion regarding how EPA can use both periodic tests and continuous monitoring data to achieve the objective of the NSPS program. The first objective of an NSPS is to ensure that an affected source installs and operates the best demonstrated control technology.[6] EPA selects a numerical emission limit to reflect the performance of the best system of emission reduction when properly operated and maintained. The required performance test verifies the ability of the source to meet that emission limit. The second objective of an NSPS is to ensure that the source complies with the general duty to properly operate and maintain its equipment.[7] I believe EPA recognized that performance tests are time consuming and expensive to perform, and that continuous monitors could play an important surveillance role in verifying a source's general duty to operate equipment consistent with good air pollution practices, but this surveillance role did not contemplate using the continuous monitoring data to verify whether the emission limit of a "periodic" emission standard was being met. EPA determined that continuous monitors could be useful in identifying periods of excess emissions. Reports of excess emissions, in turn, could provide the Agency with information to determine if a source is meeting its general duty requirements to operate and maintain equipment to minimize emissions. EPA also realized that the continuous monitors (because of their capability of continuous measurements) identify all periods of excess emissions, including those that are not the result of improper operation of control equipment. EPA acknowledged that excess emissions encountered during start-up, shutdown, and malfunctions are generally unavoidable and should not be attributed to improper operation and maintenance. I also believe EPA recognized that process and pollution control equipment does not always perform as designed and thus excess emissions, which occur as a result of inherent variability or fluctuation within a process, should not be attributed to improper operation and maintenance of the control technology.

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[4] 49 Fed. Reg. 2058 (January 17, 1984).
[5] 54 Fed. Reg. 34008 (August 17, 1989).
[6] Section 111 of the Clean Air Act states, "a standard of performance shall reflect the degree of emission limitation and the percentage reduction achievable through application of the best technological system of continuous emission reduction … the Administrator determines has been adequately demonstrated."

Accordingly, in the kraft pulp mill NSPS, EPA established both a periodic Method 9 opacity and a parallel continuous monitoring opacity standard. The periodic opacity limit is 35 percent when measured by Method 9; but when continuous monitoring is used, periods in excess of 35 percent opacity are not violations unless more than 6 percent of the readings (excluding startup, shutdown, and malfunction) in a calendar quarter exceed 35 percent. In other words, there is a 6 percent de minimis level when compliance with the opacity limit is based on continuous monitoring data.[8] EPA tempered the stringency that would have resulted from the use of any or all of the continuous opacity data from the monitors by providing a de minimis exceedance level in recognition of the frequency of measurement.

2.3 Numerical Limits

Finally, an example of the adjustment of the stringency of an emission standard by modification of the numerical limit is EPA's revision to the NSPS for the primary aluminum industry. EPA originally promulgated a fluoride emission limit of 1.9 lb/ton of aluminum produced for prebake plants and 2.0 lb/ton for Soderberg plants. Shortly after promulgation, several aluminum companies filed petitions for administrative review of the NSPS arguing that the emission limits could not be achieved at all times - even by the best-controlled facilities. In response to the petition for review, EPA embarked on a program to collect additional data from the newest aluminum smelter in the U.S. After analyzing the new data, EPA concluded that the petitioners' argument was valid. To rectify the compliance problem, EPA reiterated the original emission limits but added regulatory language stating that emissions between 1.9 and 2.5 lb/ton for prebake plants and 2.0 and 2.6 lb/ton for Soderberg plants would be considered to be in compliance.[9] These excursions above the originally promulgated standard were allowed by EPA to account for the inherent variability of the fluoride emissions from the aluminum production process. The amended rule allowed for those excursions expressly in conjunction with a new requirement to conduct performance tests more frequently – monthly instead of annually, as originally required. In sum, EPA adjusted the stringency of the standard using a combination of increased testing frequency with a relaxed numerical limit to make the emission standard consistent with the underlying data.

[7] The "General Duty" provision of the NSPS is codified in Title 40, Code of Federal Regulations, §60.11(d).
[8] See 40 CFR Sections 60.282(a)(1)(ii) and 60.284(e)(1)(ii).

3. Methods of Measuring Opacity

It is important to recognize that opacity is neither a pollutant nor an emission. Rather, opacity is the degree to which PM emissions reduce the transmission of light and obscure the view of an object in background.[10] It is my opinion that the consensus among environmental professionals is that opacity is best used as an indicator of proper operation and maintenance of PM control equipment. Using opacity as a surrogate for predicting PM emissions is less straightforward. It has been my experience that there is no strong correlation between opacity readings and PM emissions, and the relationship between opacity readings and the mass of PM emitted can vary dramatically among different sources. The relationship between opacity and PM emissions must be established for each source, and that relationship can change because the relationship is dependent on a number of variables including particle size, shape, and color.

3.1 EPA Method 9

Historically, the method used by a regulatory agency to verify that a source was operating and maintaining its PM control technology in accordance with good engineering practices was that of visual observations of the stack plume, often conducted beyond the fence line of the facility. Such observations could be done only infrequently (and still can be done only infrequently). Conducting opacity observations is a labor-intensive proposition. One observer, who must be qualified and certified in accordance with the requirements of EPA Method 9, is required per stack or per observation. EPA Method 9 requires the observer to record readings at 15-second intervals to the nearest 5 percent opacity. To be valid, a minimum of 24 observations must be recorded. Equally important, EPA Method 9 contains a number of requirements for conducting opacity readings that inherently limit the frequency at which such readings can be performed. For example, §2.1 of EPA Method 9 states, . . . "the qualified observer shall stand at a distance sufficient to provide a clear view of the emissions with the sun oriented in the 140° sector to his back."[11] Thus, from a "requirements perspective," Method 9 observations can only be conducted a small fraction of the time that a plant can operate and, specifically, can not be conducted during a significant portion of a source's potential operating hours (e.g., at night, when precipitation is falling, etc.).

[9] 45 Fed. Reg. 44202 (June 30, 1980).
[10] See, for example, Title 40, Code of Federal Regulations, section 60.2.
[11] Title 40, Code of Federal Regulations, Part 60, Appendix A, Method 9, §2.1.

There are also practical and cost considerations that limit the frequency at which regulatory agencies can reasonably be expected to conduct Method 9 observations. Perhaps the most obvious is the amount of manpower required -- to drive to a source, to obtain permission/clearance to enter the facility (when necessary), to properly position the observer with respect to the sun and the stack (per Method 9 requirements), and to take opacity readings for perhaps up to 1 hour. As a result of the manpower requirements and given all of the other duties of agency field personnel, Method 9 opacity readings have typically been conducted no more than once or twice per year at major sources. If there is a single, most prevalent schedule, it is for the regulatory agency to dispatch a certified observer to conduct Method 9 opacity readings concurrently with the source's annual PM emission tests. Thus, by combining the annual PM stack tests with Method 9 observations, the regulatory agency is able to establish at least one data point that relates PM emissions to a corresponding set of opacity readings in at least a general way.

3.2 COMS

COMS, on the other hand, is an instrument system designed to measure the attenuation of projected light due to the absorption and scattering of the light by PM in a gas stream. The basic components of a COMS are a light source, a retroflector (essentially a mirror), and a light detector. In a typical application, light travels from the light source across the gas stream to the retroflector, and then is reflected back through the gas stream to the light detector. As light travels through the gas stream some will be absorbed or scattered by the PM and not reach the detector. The transmittance through the gas stream is reduced, allowing only a percentage of the original light intensity to be measured by the detector. Opacity is related to transmittance by the following expression.

$$Opacity\ (\%) = 100 - Transmittance\ (\%)$$

In order to produce acceptable data, a COMS must meet the performance requirements set forth by EPA in Performance Specification 1 (PS-1).[12] Although COMS technology is relatively simple, in my opinion COMS measurements can nevertheless be subject to inaccuracies and biases, and it is noteworthy that all of the typical operating problems with COMS (e.g., misalignment of the transceiver and the retroreflector; dirt on optical surfaces; etc.) result in the readings being higher than the true opacity. Stated another way, typical breakdowns in the operation of COMS tend to produce readings that are biased high.

[12] Title 40, Code of Federal Regulations, Part 60, Appendix B, Performance Specification 1.

In 1996, Tom Rose prepared a report examining the potential errors in COMS measurements.[13] Basing his analysis on the measurement deviations permitted by PS-1, Mr. Rose concluded that the potential COMS measurement error is +7.5 percent opacity. Mr. Rose went on to conclude:

> COMS are useful as an indicator of baghouse performance but should not be used as the deciding factor to measure violations unless the 7.5% margin of error is used. As with any measurement system, knowledge of the errors associated with the measurement is necessary in the compliance/non-compliance decision process.

To date, EPA has not promulgated any significant quality assurance (QA) requirements to detect and correct such problems after certification – perhaps because COMS is neither a reference method nor the specified compliance method for EPA-developed opacity standards. In my opinion, without such QA requirements it is difficult to assess the accuracy of ongoing COMS measurements.

4. Statistical Considerations Related to the Stringency of Emission Standards

Over the past 30 plus years, I have examined numerous emission datasets. These datasets have included SO_2 emissions, NO_X emissions, and opacity data. Almost without exception, these data tend to fit a lognormal distribution. A lognormal distribution is a skewed distribution, one that is characterized by having an elongated tail instead of the classical bell-shaped curve characteristic of a normal distribution. It is relatively easy to visualize why emission distributions are lognormal. Emissions are naturally limited at zero (i.e., emissions cannot be negative), but for practical purposes, there is almost no upper bound limit to how high any specific air pollutant emission can be. Of course, opacity emissions are mathematically constrained at 100 percent and also at 0 percent. However, because of the installation and operation of highly efficient PM control technology, opacity readings also tend to be lognormally distributed with the tail or skewness being toward that of the higher opacity readings -- such as the example curve shown in Figure 1 of Appendix A.

The form of the distribution of opacity readings is very important, especially in the case where measurements or readings are conducted periodically, rather than continuously. As explained

[13] "Analysis of Errors in Continuous Opacity Measurement Systems," Tom Rose, prepared for Steel Manufacturers Association, December 2, 1996.

below, when measurements are conducted only periodically, the results obtained will be those that occur most frequently.

4.1 Statistically-Based Solution

One way of approaching the stringency issue is to pose the question - how often would Method 9 readings have to be taken in order to record at least one opacity excursion in excess of 20 percent? The probability ("P") of making a number of observations ("n") and not observing an event that occurs randomly twice out of every 100 possibilities (i.e., frequency of occurrence = 2%) is given by the equation $P = 0.98^n$. Likewise, the probability of making n observations and observing an event that occurs only two times out of every 100 possibilities is given by $P = (1-0.98^n)$. We have solved this equation for a series of observations (n) and plotted the results as Figure 2 of Appendix A. Figure 2 and the solution to the equation illustrates that if you wish to be 95 percent confident in observing an event that occurs 2 percent of the time, then you must make at least 148 random observations. Likewise, if you wish to be very confident (i.e., 99 percent) in observing an event that occurs 2 percent of the time, then you must make 228 random observations.

This statistical analysis relates to Method 9 observations as follows. Suppose a source has 6-minute average opacity readings in excess of 40 percent 2 percent of the time. Further, suppose that we wish to have a 95 percent confidence of detecting at least one such exceedance. Then, our statistical analysis shows that an observer would have to conduct 148 random Method 9 observations in order to be 95 percent certain of recording at least one exceedance.

This statistical analysis is independent of time. That is, if the Wyoming DEQ wished to record, at a 95 percent confidence level, one exceedance during a calendar quarter then the agency would have to perform 148 randomly spaced Method 9 observations during the quarter. If the agency wished to record, at a 95 percent confidence level, one exceedance during a calendar year then the agency would have to perform 148 randomly spaced Method 9 observations during the year. Thus, obtaining 148 random opacity readings would effectively require the performance of 148 Method 9 observations of a single stack. Clearly, performing 148 Method 9 tests every quarter (more than one test per day per stack) or 228 per quarter if a confidence level of 99 percent were desired, is beyond what any regulatory agency could reasonably be expected to perform.

4.2 Additional Statistical Approach

As previously discussed, periodic emission standards are those that were developed using periodic and limited emission testing data. Accordingly, the supporting database tends to be insufficient to characterize the variability in either the process or the air pollution control technology. For that reason, such standards are typically set at levels that may well be exceeded during any given test. Typically, such standards are set at a 5 to 10 percent probability of failure level along with the implicit assumption that compliance tests can only be conducted infrequently.

In 1995, Robert Ajax authored a paper that discussed the relationship of measurement frequency and the stringency of technology-based emission limits.[14] Table 2 from the Ajax paper is reproduced below.

Number of Exceedances Expected

	Frequency of Compliance Computation			
Probability Level of Standard	Every 6 Min.	Every 6 Hrs.	Daily	Annually
90%	8,760/yr	219/yr	36/yr	1/10 yr
95%	4,380/yr	110/yr	18/yr	1/20 yr

Mr. Ajax's tabulation compliments the statistical approach presented in Section V.4.1. That is, Mr. Ajax's table enumerates the number of exceedances expected as a function of measurement frequency and probability of compliance. For example, if a source were in compliance 95 percent of the time and compliance were measured every 6 minutes, then 4,380 exceedances would be expected per year. On the other hand, if compliance were measured daily, only 18 exceedances would be expected per year.

4.3 Combining the Statistical Approaches

Section V.4.1 of this report examined the proposition - how frequent must one make measurements in order to determine a specified (e.g., 2 percent) exceedance rate, at various levels of confidence. Given a measurement frequency, Section V.4.2 enumerates the number of expected exceedances as a function probability of compliance. These two analyses approach the question in more or less opposite directions, yet reach a consistent conclusion – that the stringency of an emission standard is strongly dependent on the frequency of measurement. In other words, increasing the measurement frequency will increase the stringency of a standard

[14] "The Effect of Compliance Test Frequency on the Stringency of Technology Based Standards," Robert L. Ajax, March 9, 1995.

unless one of the other elements (e.g., averaging time) is adjusted. Thus, it is my opinion that switching from Method 9 to COMS to enforce Wyoming 's opacity standard without a revision to one of the other elements of an emission standard (e.g., averaging time or numerical limit) results in a significantly more stringent opacity standard.

5. Recent Recognition by States that COMS is More Stringent than Method 9

Recently, a number of states have begun to revise their opacity regulations to account for measurement with continuous monitors while maintaining a periodic Method 9 compliance test. Such regulatory revisions are quite consistent with the action taken by EPA in the previously discussed kraft pulp mill NSPS.

5.1 Alabama

For a number of years, coal-fired utility boilers in Alabama have been subject to a visible emission standard, which is codified as Alabama Department of Environmental Management (ADEM) Rule 335-3-4.01(1). The visible emission standard was not developed using continuous monitoring data since such data were not available at the time the standard was developed more than 30 years ago. Under the Alabama rule, compliance with the visible emission standard is determined periodically by a certified observer making opacity readings in accordance with EPA Method 9. Alabama Rule 335-3-4.01(a) limits opacity to 20 percent, as determined by 6-minute averages. The 20 percent opacity limit in the current Alabama regulations and included in the Alabama SIP was developed as a periodic standard to be verified with Method 9. However, under ADEM Rule 335-3-4-.01(1)(b), visible emissions up to 40 percent are permitted during one 6-minute period in any 1-hour period, and emissions during startup, shutdown, and load change events are excluded.

Recently, the Alabama Department of Environmental Management (ADEM) proposed to amend its visible emissions regulation. Specifically, ADEM proposed to amend Rule 335-3-4-.01 by adding 335-3-4.01(3), 335-3-4.01(4) and 335-3-4.01(5). New paragraph (3) sets forth the requirements that a COMS must meet in order to be used to determine compliance with the visible emissions rule, which is provided in paragraph (1) of this rule. New paragraph (4) is the linchpin of ADEM's proposed rule amendment. Paragraph (4) states, "the permittee will not be deemed in violation of Rule 335-3-4-.01(1) if the non-exempt excess emissions periods do not exceed 2.0 percent of the source operating hours for which the opacity standard is applicable and for which the COMS is indicating valid data." This is clear evidence that ADEM understands

the difference between periodic and continuous standards, and recognizes that its 20 percent periodic (Method 9) opacity limitation cannot be achieved by a source operating its equipment consistent with good air pollution control practices during all operating periods, even when non-exempt periods are excluded. In other words, when changing from a periodic compliance method (e.g., Method 9) to a continuous compliance method (e.g., COMS data), an accompanying change is required (i.e., creating the 2 percent exemption) to maintain the stringency of the original visible emissions standard.

5.2 North Carolina Rule

The North Carolina Department of Environment and Natural Resources recently revised the North Carolina SIP with respect to the use of COMS data for opacity. North Carolina amended its visible emissions standard to establish a "reasonable procedure" for sources using COMS to demonstrate compliance with the visible emission standard. After first deducting potentially numerous exemptions (i.e., startup, shutdown, malfunction and other scenarios under the rule), the North Carolina rule allows opacity readings in excess of the numerical limit 0.8 percent of the time.[15] Initially, EPA approved this standard, after evaluation by North Carolina and others on the grounds, in part, that the rule "is designed to provide sources using COMS the same opportunity to comply with the visible emissions rule as sources that do not use COMS devices."[16] In other words, EPA concurred that the use of COMS to determine compliance with a standard developed with the intent to be enforced with Method 9 would result in a more stringent standard unless the numerical limit was revised upward or a de minimis excess emission period was excluded. EPA's initial approval was a direct final rule (one EPA deemed non-controversial) that also provided for subsequent withdrawal of approval to consider any adverse comments. EPA received such a comment, and, accordingly withdrew its approval of the North Carolina rule. However, it is important to note that EPA did not withdraw its statement about the effect of the North Carolina rule as equalizing the periodic and COMS standards.[17] Subsequently, EPA has proposed to approve, in its entirety, the Visible Emissions portion of the North Carolina State Implementation Plan (SIP).[18]

[15] The numerical opacity limit in the North Carolina rule for sources in operation prior to July 1, 1971 is 40 percent.
[16] 68 Fed. Reg. 33874 (June 6, 2003).
[17] 68 Fed. Reg. 46101 (August 5, 2003).
[18] 70 Fed. Reg. 28496 (May 18, 2005).

5.3 Ohio

Similarly, following the current trend of promulgating continuous standards, which are modified to be equivalent to historical periodic standards, the Ohio Environmental Protection Agency in 2002 revised its regulations with respect to the use of COMS data. Ohio revised Rule 3745-17-03(B), to state that during each calendar quarter, the permittee shall be deemed in compliance with the opacity standard if the following conditions are met:

1. *The nonexempt opacity values in excess of twenty per cent opacity are less than 1.10 per cent of the six-minute average opacity values.*
2. *None of the nonexempt six-minute average opacity values exceeds sixty per cent.*
3. *The total amount of time, in hours, of exempt*[19] *and nonexempt opacity values greater than twenty per cent and less than sixty per cent (not including start-up, shutdown, and malfunction exemptions) does not exceed the product of 0.10 times the actual number of hours the emissions unit was in operation during the calendar quarter.*

Strangely (considering EPA's recent proposal to approve a de minimis period in North Carolina discussed above) EPA is proposing to disapprove the Ohio revisions that provide for the use of continuous opacity monitoring (COM) data to determine compliance with opacity limits, but allow specified de minimis periods. Apparently, because of the de minimis exemption periods, EPA proposes to find that the Ohio revisions constitute a relaxation of the existing Ohio opacity rules.[20]

5.4 Tennessee

In Tennessee, compliance with the State's visible emissions standard is to be determined periodically by a certified observer making opacity readings in accordance with EPA Method 9. However, under Tennessee Department of Environment and Conservation (TDEC) Rule 1200-3-5-.03(5), the Technical Secretary may agree to the use of continuous opacity monitors (COMS) for determining compliance with the opacity limit after specifying in the appropriate permit the operational availability and quality assurance requirements for the COMS. For fuel burning sources, TDEC Rule 1200-3-20-.06(5)(a) defines a de minimis period for opacity in excess of the applicable opacity limit to be equal to 2 percent of facility operating time per calendar quarter, excluding periods of start-up, shutdown, and excused malfunctions. Statistically, this analysis

[19] Exempt opacity values are specifically defined in Ohio Rule 3745-17-07(A).
[20] 70 Fed. Reg. 36901 (June 27, 2005).

shows that for a fixed opacity percentage limit, COMS with a 2 percent de minimis exemption is likely to be more stringent than the same numerical percentage limit when enforced with periodic Method 9 observations and no de minimis periods.

6. COMS Data from MCC Kiln No. 2 Should Not be Assumed Credible Evidence of PM Violations.

Wyoming regulations currently allow the use of "credible evidence" or information to determine compliance but only if such evidence or information is relevant to whether the source would have been in compliance with applicable emission limits *if* the appropriate compliance test had been performed. MCC's permits specify that compliance with the PM emission limit for Kiln No. 2 be determined annually by conducting a stack test using EPA Reference Method 5.

In my opinion, there is no basis for concluding *a priori* that the CAM Plan results for MCC Kiln No. 2 can be used to determine compliance with the PM mass emission limit (expressed in the units of pounds/hour) given that the required compliance test method is EPA Reference Method 5. I believe that the variability exhibited between simultaneous COMS opacity readings and Method 5 mass emission rate determinations that were used to establish the CAM graph is so large that there is no way to say with certainty that CAM graph and Method 5 would yield equivalent results for any particular compliance tests. Data used to develop the CAM Plan for Kiln No. 2 are shown in Table 1. A plot of the data along with a "best fit" linear regression line is shown as Figure 1. A plot of the data along with a least squares regression line and the 95 percent tolerance intervals is shown as Figure 2. The tolerance intervals are constructed such that we have 95 percent confidence that 75 percent of the data points will lie within the pair of tolerance intervals. There are at least three significant technical problems with using the MCC Kiln No. 2 CAM Graph to predict non- compliance with the PM emission limit.

Table 1. MCC Kiln No. 2 CAM Data

Date	Time	Opacity, %	PM Emissions, lbs/hr
2/8/2000	07:37 – 08:41	17.6	27.36
2/8/2000	11:13 – 12:18	14.8	22.92
8/21/2001	11:22 – 12:24	4.1	6.80
8/28/2001	13:09 – 14:14	5.0	8.90
4/24/2002	14:02 – 15:08	8.6	20.75
4/24/2002	16:03 – 17:09	8.9	20.95
4/25/2002	11:06 – 12:14	21.0	28.10
8/30/2002	09:15 – 10:18	7.2	18.00
8/30/2002	11:22 – 12:24	6.0	14.80

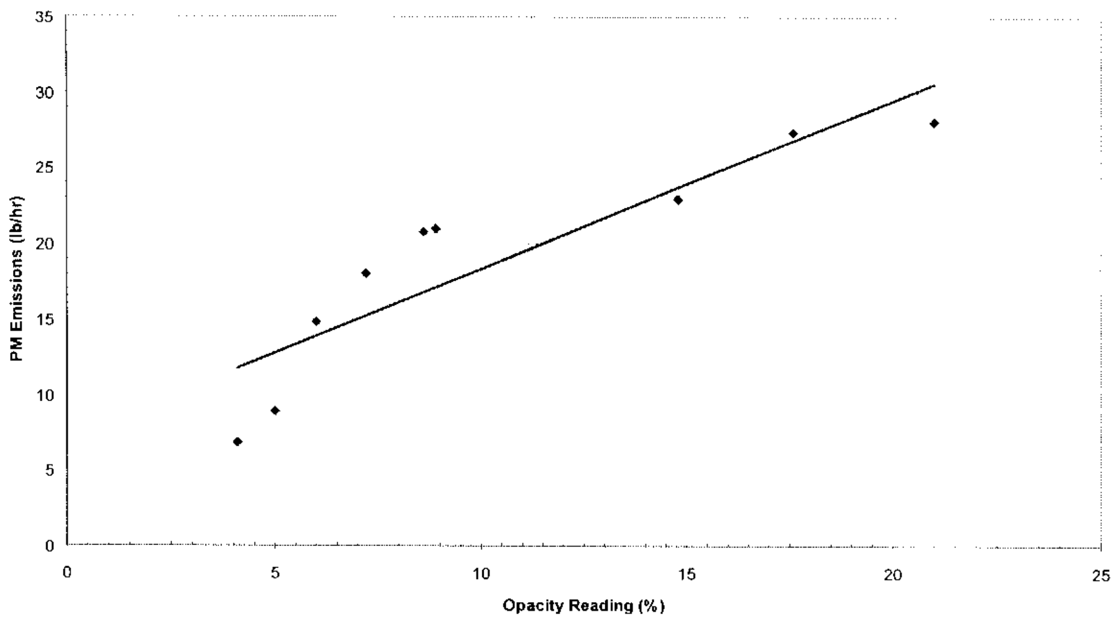


Figure 1
Basic CAM Graph for MCC Kiln No. 2

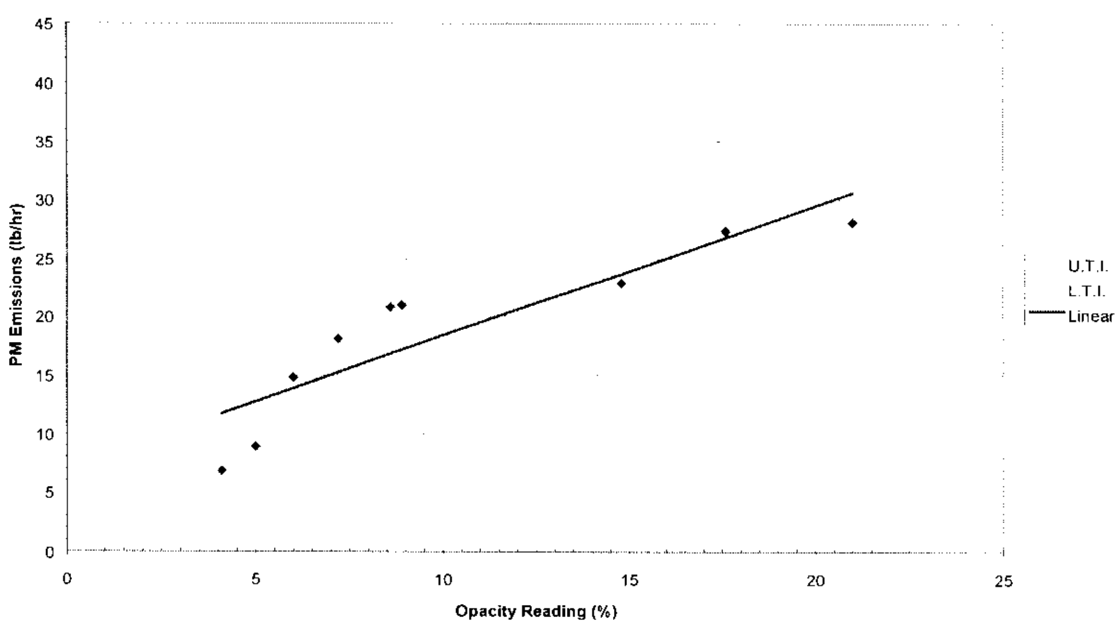


Figure 2
CAM Graph for MCC Kiln No. 2 with Tolerance Intervals

1. As the CAM Graphs clearly show, there is a tremendous amount of variability in the relationship between opacity and hourly PM emission rates. As Figure 2 shows, at 20 percent opacity, we know that (at the 95 percent confidence level) 75 percent of the time, the measured PM emission rate will be between 20.5 and 38.5 pounds per hour. Although the central estimate (regression line) 29.5 lb/hr, 50 percent of the time emissions would actually be higher and 50 percent of the time actual emissions would be lower.
2. The next technical issue is data range. The highest reported data pair is: 21 percent opacity and PM emissions equal to 28.1 lb/hr. To assert non-compliance with the Kiln No.2 PM emission limit of 29.3 lb/hr requires extrapolation beyond the limits of the data. Extrapolation beyond the limits of the data introduces uncertainly in the opacity - PM relationship that is simply unknown.
3. Lastly, there is the issue of averaging time. Compliance with the PM emission limit for MCC Kiln No. 2 must be based on the arithmetic average of three EPA Method 5 sampling runs. EPA Method 5 requires a minimum sampling time of 60 minutes. When the time required for sampling port changes along with the time to clean-up one run and to prepare for the next run are considered, the effective average time must be on the order of 6 hours.

To further document the averaging time issue, I reviewed five PM emission test reports for MCC Kiln No.2, which covered a period from February 2000 through April 2002. These five reports described a total of seven EPA Method 5 compliance tests for MCC Kiln No. 2. The elapsed time (i.e., time for the start of the first run until the completion of the third run) for the seven PM compliance tests ranged from 4 hours and 16 minutes to 5 hours and 11 minutes. The average elapsed time for a EPA Method 5 compliance test was 4 hours and 45 minutes – almost 5 hours.

MCC's compliance testing requirement is consistent with EPA regulations. For example, 40 CFR 60.8, which is a general provision applicable to facilities subject to EPA's new source performance standards, states that compliance is based on the arithmetic mean of three sampling runs using the applicable test method. Section 60.8 also states that performance (compliance) tests are to be conducted under representative operating conditions. Operations during periods of startup, shutdown, and malfunction shall not constitute representative conditions for the purpose of a performance test nor shall emissions in excess of the applicable limit be considered a violation. Likewise, 40 CFR 63.7, which is a general provision applicable to facilities subject to EPA's maximum achievable control technology (MACT) standards, contains almost identical language with respect to (1) basing compliance on the arithmetic mean of three runs and (2) conducting the performance test under representative operating conditions.

7. Conclusions

Based on the foregoing, and in addition to my conclusions contained herein, it is my opinion that:

- The MCC Kiln No. 2 opacity limit, if enforced with COMS data, would be considerably more stringent than the limit when verified with periodic Method 9 readings.
- A 20 percent opacity limit, if enforced with COMS data without de minimis relief periods, is more stringent than a 20 percent opacity limit enforced with Method 9.
- Consistent with EPA's High Priority Violations policy, Wyoming DEQ takes no enforcement action if opacity exceedances measured by COMS occur less than 5 percent of the operating time in any one quarter or less than 3 percent of operating time in two consecutive quarters.
- COMS data are best used for their originally intended purpose – to verify proper operation and maintenance of PM control technology.
- COMS, like all other measurement systems, are subject to inaccuracies, breakdowns and malfunctions. Typical operating problems (e.g., dirty optics and misalignment) tend to produce COMS readings that are biased high.
- By itself, the CAM graph for the MCC Kiln No. 2 cannot be used as credible evidence to show non-compliance with the PM emission standard.

APPENDIX A

Figure 1. Frequency Distribution of Opacity Data
[One Calendar Quarter]

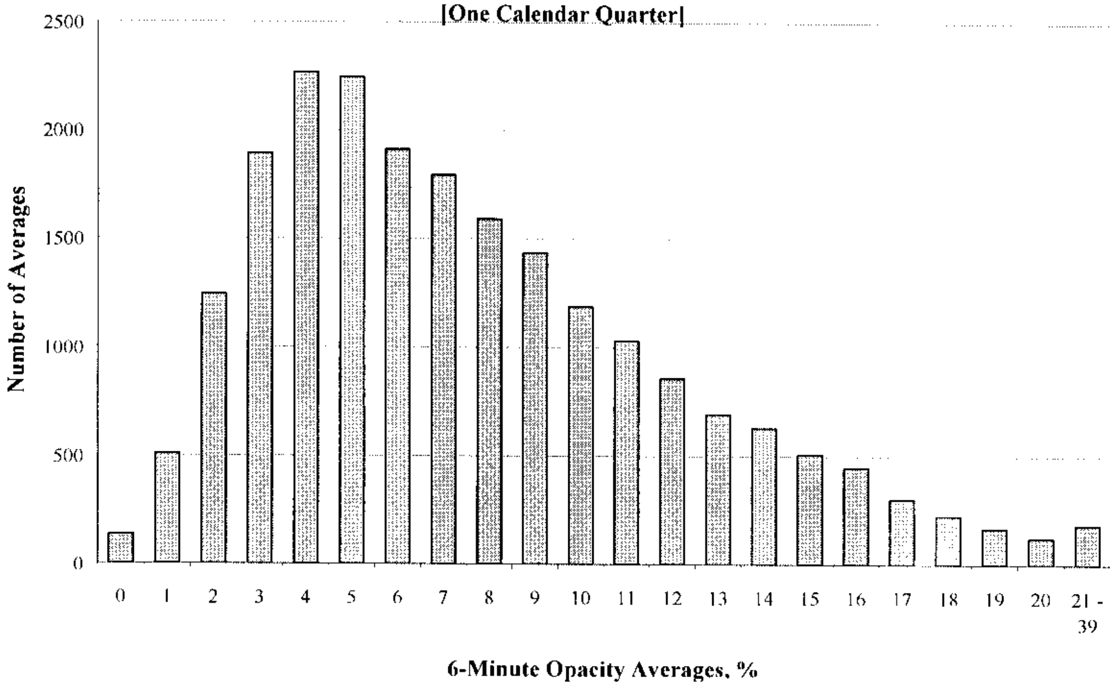
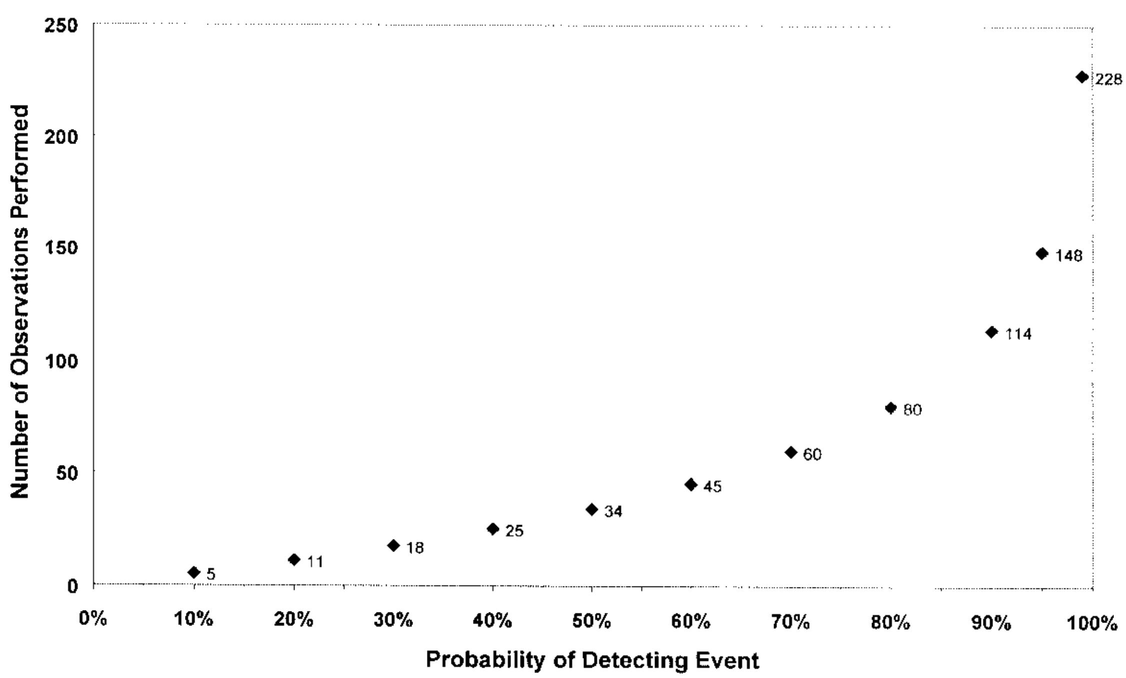


Figure 2. Frequency of Event = 2%



APPENDIX B

RALPH L. ROBERSON

EDUCATION

1971	M.S. in mechanical engineering, University of Virginia
1969	B.S. in mechanical engineering, University of Virginia

PROFESSIONAL CERTIFICATION

Professional Engineer: Virginia

SPECIALIZED TECHNICAL EXPERTISE

- Expert testimony: statistical analyses, achievability of emission limitations, probability of exceedances, and status of emerging continuous monitoring technology.
- Data analysis: use of state-of-the-art statistical techniques to estimate emissions and to analyze emission data: to determine achievability of emission standards; to assess impacts on ambient air quality; to evaluate control technology effectiveness; and to estimate exposure to various air pollutants.
- Continuous emission monitoring (CEM) systems: regulatory analysis, alternative monitoring methods and procedures, quality assurance/quality control plans, and design/purchase specifications.
- Hazardous air pollutants: emissions from electric utility boilers, regulatory analysis, risk analysis, and assessment of control technology performance.

PROFESSIONAL EXPERIENCE

Mr. Ralph Roberson is one of the founders of RMB Consulting & Research, Inc. and serves as president of the company. His recent experience include detailed statistical analysis of mercury emission data and statistical assessment of data collected by continuous particulate matter (PM) monitors. He provided technical assistance to electric utility companies in complying with EPA's mercury information collection request (ICR), analyzing hazardous air pollutant emission data from coal- and oil-fired power plants in order to estimate accurately power plant health risks; conducting CEM quality assurance training at six coal-fired power plants that are subject to EPA's Part 75 CEM monitoring requirements; participating in the Acid Rain Advisory Committee (ARAC) process that assisted EPA's development of regulations pursuant to the acid rain provisions of the 1990 Clean Air Act Amendments; managing a project that utilized state-of-the-art statistical techniques to demonstrate that short-term ambient air quality standards can be protected by long-term source emission standards; managing a nationwide exposure assessment of asthmatics to short-term elevated SO_2 concentrations; directing a preliminary impact analysis of the effects of electric utility plants on short-term ambient NO_2 concentrations; serving as peer reviewer for EPA's development of toxic air pollution emission factors for combustion sources; and conducting an analysis to estimate the impact on ambient air quality and MEI risks of co-firing

hazardous wastes in utility boilers.

Mr. Roberson has conducted a nationwide risk assessment of trace pollutant emissions from coal- and oil-fired utility plants. This project involved development of trace pollutant emissions factors, specification of nine reference utility plants, and coordination of computerized modeling utilizing EPA's HEM and EPRI's AERAM. He also managed a project that assessed radiological risks posed by emissions from coal-fired power plants. Activities in this effort involved developing a radionuclide sampling protocol, coordinating radiochemical analysis of samples, preparing quality assurance procedures, and preparing input parameters for AIRDOS-EPA computerized modeling runs.

In addition to these projects, Mr. Roberson has performed particle size analysis; directed emission tests for criteria and hazardous air pollutants (particulate matter, sulfur dioxide, oxides of nitrogen, mercury, lead, and fluoride); and consulted with industry to define and solve environmental and industrial hygiene problems.

Mr. Roberson was project leader on a U.S. EPA project to develop a National Emission Standard for hazardous air pollutants from the oil shale industry. He also worked with EPA's Oil Shale Working Group, which was responsible for directing development of the Pollution Control Guidance Document for Oil Shale. In a series of tasks for EPA's Division of Stationary Source Enforcement, he worked with the national continuous emission monitoring (CEM) program to assess levels of source compliance, evaluate reporting requirements, and review excess emission and performance specification test reports. He also directed development of a computerized, nationwide CEM data base under a task coordinated through Edison Electric Institute and all EPA regional offices as well as many state and local air pollution control agencies.

PROFESSIONAL AFFILIATIONS

Air and Waste Management Association
American Society for Mechanical Engineers
Sigma Xi

SELECTED PRESENTATIONS AND TECHNICAL REPORTS

"Technical Review Comments, EPA's 'Proposed National Emission Standards for Hazardous Air Pollutant; and in the Alternative, Proposed Standards of Performance for New and Existing Stationary Sources: Electric Utility Steam Generating Units' and 'Supplemental Notice for the Proposed National Emission Standards for Hazardous Air Pollutant; and in the Alternative, Proposed Standards of Performance for New and Existing Stationary Sources: Electric Utility Steam Generating Units," (with R. McRanie) prepared for the Utility Air Regulatory Group, Washington, DC, June 2004.

"Expert Report on Alternative Methods for Measuring Opacity for Coal-Fired Power Plants," prepared for Georgia Power Company, December 2003.

"Characterizing Variation in Mercury Emissions from Coal-Fired Power Plants," prepared for EPRI, Palo Alto, CA, 1005401, June 2003.

"Characterization of 'Longer-Term' Mercury Emissions from Coal-Fired Power Plants," (with P. Chu et al.) in *Proceedings of the Combined Power Plant Air Pollution Control Mega Symposium,* Washington, DC, May 2003.

"Expert Report on Stringency of Opacity Standard Based on Continuous Opacity Monitoring (COM) Data," prepared for Public Service New Mexico, December 2002.

"Continuous Emission Monitoring Guidelines - 2002 Update," (with R. Berry and D. Sanders) prepared for EPRI, Palo Alto, CA, 1004179, September 2002.

"Status of Particulate Matter Continuous Emission Monitoring Systems," prepared for EPRI, Palo Alto, CA, 1004029, October 2001

"Analysis of the Stringency of the Tennessee Opacity Standard Based on Continuous Opacity Monitoring System Measurements as Compared to Periodic Method 9 Readings," prepared for Tennessee Valley Authority, July 2001

"Results of Continuous PM Monitor Testing at Pleasant Prairie Power Plant," (with J. Koning and C. Dene) presented at the EPRI CEM Users Group Meeting, Charlotte, NC, May 2001

"Status of Mercury Continuous Emission Monitoring Systems," prepared for EPRI Energy Conversion Division, September 2000

"Evaluation of Continuous Particulate Matter (PM) Monitors for Coal-Fired Utility Boilers with Electrostatic Precipitators," (with C. Mitchell and C. Dene) presented at the EPRI CEM Users Group Meeting, Cincinnati, OH, May 1999

"EPA's Mercury Information Collection Request," presented at the Electric Utilities Environmental Conference, Tucson, AZ, January 1999

"Status of CEM Systems for Particulate Matter (PM) Emissions and Selected Non-Criteria Pollutants," prepared for EPRI Energy Conversion Division, September 1998

"Status of EPA's Continuous Particulate Mass (PM) Monitor Demonstrations," presented at the EPRI CEM Users Group Meeting, Denver, CO, May 1997

"Mercury Measurement Methods for Electric Utility Plants" (with B. Nott and P. Chu), presented at A&WMA Conference, Acid Rain and Electric Utilities II, Scottsdale, AZ, January 1997

"Mercury and Other Trace Elements in Coal" (with S. Baker), EPRI TR-106950, prepared for Electric Power Research Institute (1997)

"Mercury Speciation Methods for Utility Flue Gas" (with D. Laudal, et al), *Fresenius Journal of Analytical Chemistry,* in press

"Status of CEM Systems for HAP Emissions," presented at the EPRI CEM Users Group Meeting, Kansas City, MO, May 1996

"Status of Flue Gas Mercury Measurement Methods for Electric Utility Power Plants" (with B.

Nott), prepared for the Electric Power Research Institute (1996)

"Overview: Mercury Emissions from Fossil Fuel-Fired Electric Generating Units" (with S. Baker), prepared for the Florida Electric Power Coordinating Group (1994)
"Review and Critique of EPA's Proposed CEM Accuracy and Bias Test Procedures," prepared for Utility Air Regulatory Group (1992)

"Review of Proposed Amendments to New Mexico Air Quality Control Regulation 603 - Coal Burning Equipment - Nitrogen Dioxide," prepared for Arizona Public Service Company (1991)
"Analysis of Ethyl Emission Test Data" (with D. Dickey), prepared for the Ethyl Corporation (1990)

"Continuous Emission Monitoring and Quality Assurance Requirements for New Power Plants." Presented at the 1989 Joint Power Generation Conference, Philadelphia, PA (1989)

"Compliance with Appendix F Requirements by Subpart Da Facilities During 1988," prepared for Utility Air Regulatory Group (1989)

"Assessment of Ambient Air Quality Impacts from Co-Firing Hazardous Wastes in Electric Utility Boiler," prepared for Utility Air Regulatory Group (1989)

"Degree of Protection Against NAAQS Violations Provided by 30-Day Rolling Average Emission Limits at Public Service of Indiana Cayuga Generating Station" (with others) (1989)

"Assessment of Risks Posed by Radionuclide Emissions from Coal-Fired Power Plants," prepared for Utility Air Regulatory Group (1988)

"Assessment of the Impact of the Subpart Db New Source Performance Standards on Electric Utility Auxiliary Boilers," prepared for Utility Air Regulatory Group (1987)

"Quality Assurance Plan for Continuous Emission Monitoring Systems," prepared for Intermountain Power Project (1986)

"Nationwide Assessment of Risks Posed by Coal and Oil Combustion in the Electric Utility Industry," prepared for Utility Air Regulatory Group (1986)

"Continuous Emission Monitoring Guidelines" (with T. Eggleston), EPRI CS-3723, prepared for Electric Power Research Institute (1984)

"Quality Assurance Plan for Continuous Emission Monitoring Systems," prepared for Montana Power Company (1984)

"Characterization of Radionuclide Emissions from Coal-Fired Utility Boilers," prepared for Utility Air Regulatory Group (1983)

EMPLOYMENT HISTORY

RMB Consulting & Research, Inc.	President	1994 to present

Systems Applications International	Vice President	1990-1994
Roberson Pitts, Inc.	President	1987-1990
Kilkelly Environmental Associates, Inc.	Vice President	1981-1987
Research Triangle Institute	Senior Environmental Engineer	1979-1981
Commonwealth Laboratory, Inc.	Manager, Technical Services Division	1973-1979
Newport News Shipbuilding and Dry Dock	Senior Analyst	1971-1973